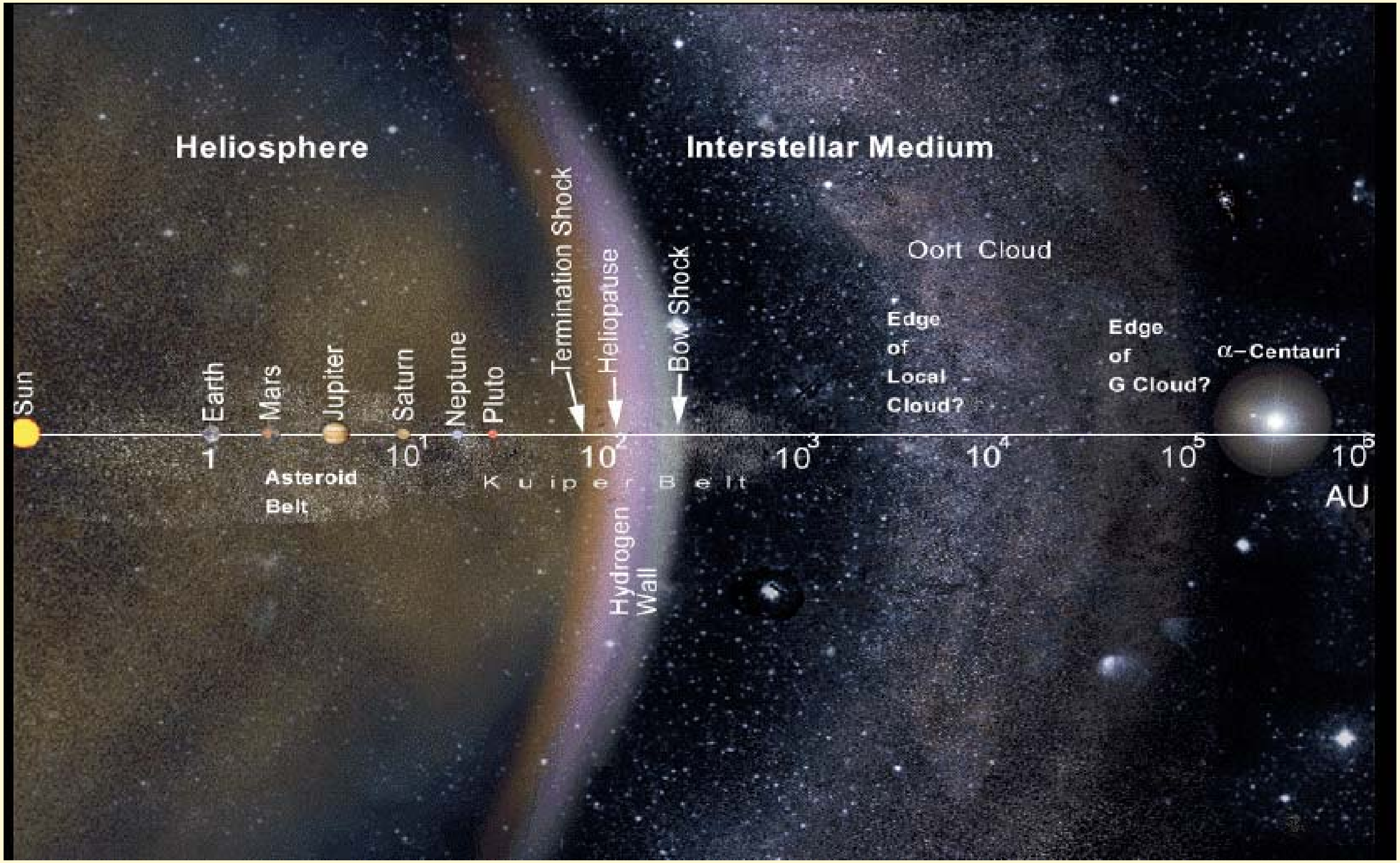
Long Duration Processing in Low Gravity



Uniqueness of Low Gravity Processing

Containerless Processing Technology

Low-g versus Earth-g: Some Surprises

D. Gillies/MSFC

J. Rogers/MSFC

R. German/Penn State

Materials Processing in Low Gravity

Uniqueness

Donald C. Gillies

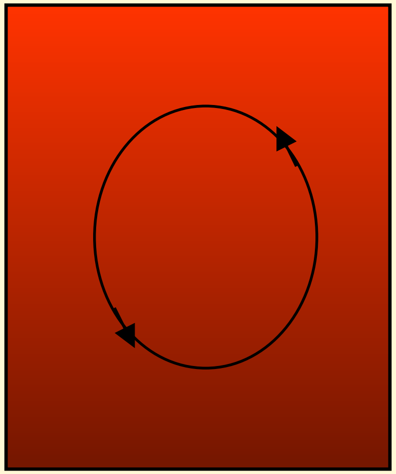
MSFC

In-Space Fabrication and Repair Research Workshop

July 8, 2003

Effects of Reduced Gravity on Processing

- **Reduction or Eliminates Buoyancy Driven Convection**
  - Suppresses Thermal and Compositional Fluctuations
  - Will influence Mixing of Materials (Good or Bad!)
  - Simplifies or Allows Precise Measurement of Thermophysical Properties
    - (underrated, always needed for modeling, especially when predicting behavior in microgravity)
  - Vastly simplifies the Evaluation of the Importance of the Various Heat and Mass Transport Processes
  - Establishes Diffusion-Limited Conditions During Solidification
  - Free surfaces very susceptible to surface tension driven convection (magnetic fields may help here)



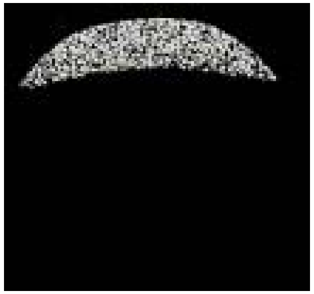
Effects of Reduced Gravity on Processing

- **Reduces or Eliminates Sedimentation**
  - Facilitates Preparation of Heterogeneous Mixtures or Suspensions
  - Influences mixing
  - Reduces or Prevents Unwanted Phase Separation
  - Allows Enhanced Containerless Solidification Processes

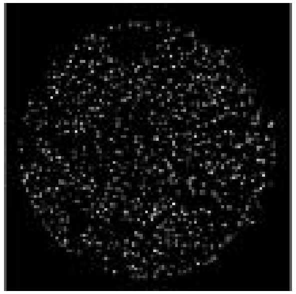
Coarsening in lead-tin alloy

Prof. Voorhees, Northwestern University

1g



tin phase floating



μg

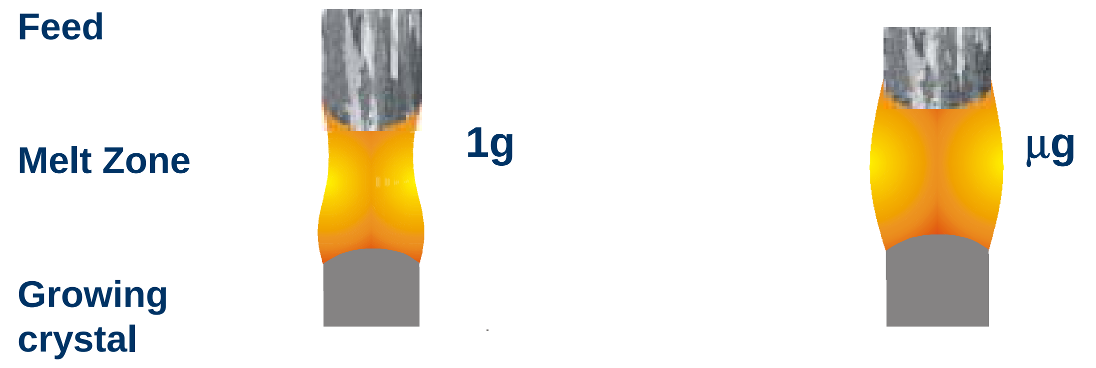
even distribution, shuttle flight STS-83

Permits quantitative measurements

Effects of Reduced Gravity on Processing

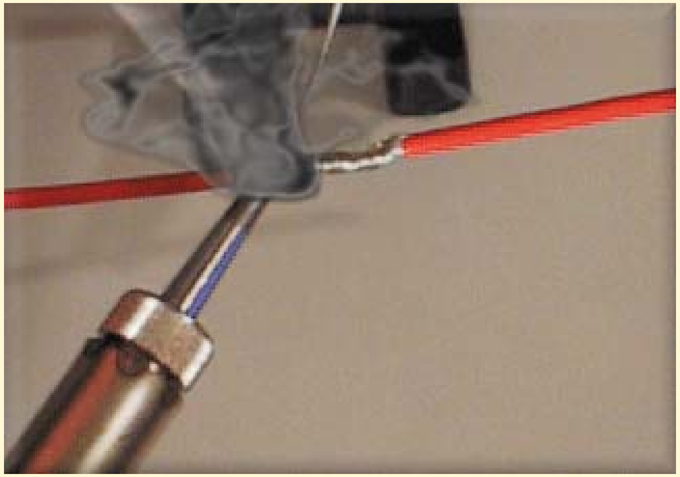
- **Eliminates Hydrostatic Pressure**
  - Facilitates the Containment of Liquids by their Surface Tension allows Float Zone Processing of Low Surface Tension Materials
  - Eliminates or Reduces Stresses Arising from the Material's own Weight
  - Enhances possibility of obtaining "Detached Solidification"
    - Defect-controlled single crystals

Schematic of float zone processing



Effects of Reduced Gravity on Processing

- **Possible "gotchas"**
  - No stabilizing g-vector; convection from residual mg may be enhanced
  - Sudden change in gravity level could ruin process
  - Materials may not mix adequately
  - Surface tension driven convection causes stirring
  - Forced convection may be necessary for adequate cooling
  - Forced convection may be necessary to remove gaseous products
    - e.g. to remove smoke during soldering, welds



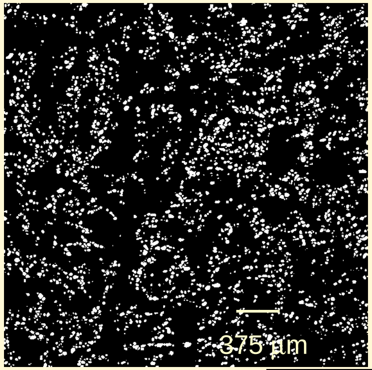
Coarsening in Solid-Liquid Mixtures Experiment

Peter Voorhees, Northwestern University

The understanding of the kinetics of coarsening over long time periods is essential for the design of materials used at high temperatures.

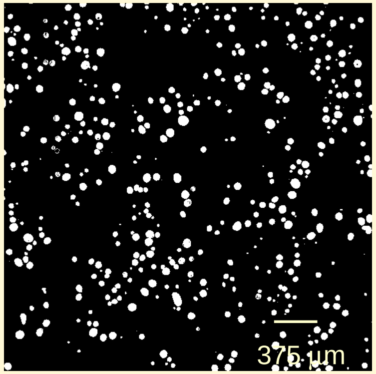
Why:

- Coarsening, or the growth of strength-giving small particles, weakens materials over time. Predicting the long term behavior of technological materials is vital to the successful use of many industrial products, especially those used at high temperatures.

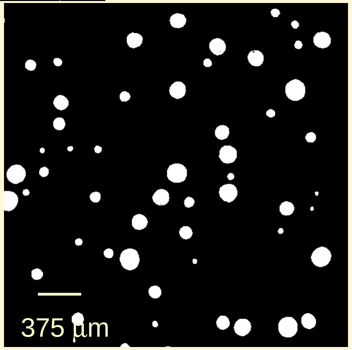


t= 0hr

Solid Sn particles in a liquid Pb-Sn alloy.



t= 0.6 hr



t= 24 hr

The size of the particles increases with coarsening time t.

In many materials, such as Ni-based superalloys used in jet engine turbine blades, this increase in size has a dramatic effect on the properties of the alloy.

How:

- Coarsening in solids is too slow to be studied on Earth, while liquid-solid mixtures suffer from sedimentation and convection. The alloy system used, namely tin particles in a lead liquid, overcomes both these difficulties with a long term microgravity experiment.
- The work will be done in the Microgravity Science Glovebox.

Impact:

- This work will help fill a gap in the understanding of both the initial stages of coarsening, and the equilibrium state reached after long time periods.
- Data from a previous flight have enabled a small business in Evanston to develop software now being used by Pratt and Witney to design turbine blades.

"….the proposed experiment has potential significance and important impact on the materials science research community……the panel feels so strongly about the potential utility of these data that they make specific recommendations for the dissemination of the data." ICR Panel, Mar 2000.

MS2	Final Peer Review Date: 2000	Flight Hardware Availability: 2002

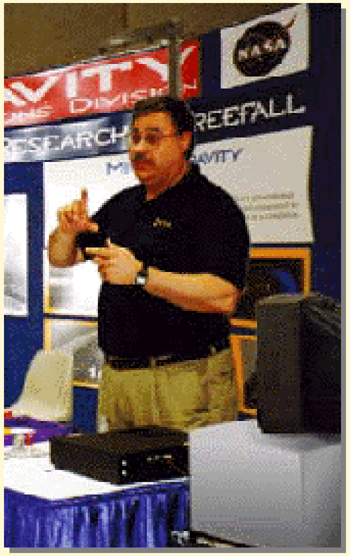
Acta Metall., *48*, *2689, (2000).*

The Old Microgravity Program

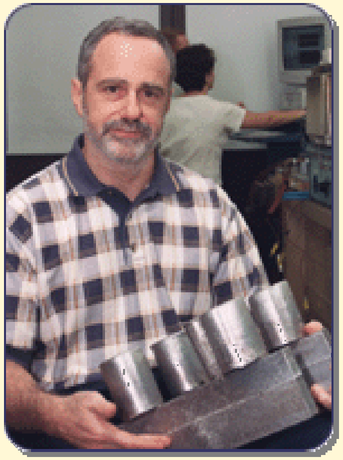
Materials Science Discipline Working Group

Tim Anderson

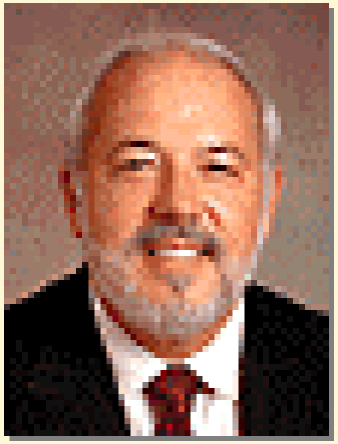
Bob Sekerka



Mike Wargo

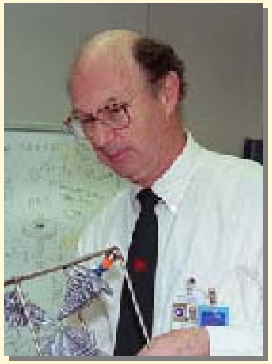


Jon Dantzig



John Rabolt

Mike Jaffe



Don Gillies

Rohit Trivedi

Not present

Dick Hopkins   John Perepezko   Gene Benton

Our Current Orbit – And Beyond: More Details on the Organizing Questions

	ORGANIZING QUESTION	DETAILED QUESTIONS / TOPICS
1	How can we assure the survival of humans traveling far from earth?	Our program content in this area is primarily radiation materials, but we may also include biosentinels and related concepts
2	What must we know about how space changes life forms, so that humankind will flourish?	
3	What new opportunities can our research bring to enrich lives on earth and expand understanding of the laws of nature?	1 How does the space environment change the behavior of physical and chemical processes and the technologies that rely on them?
		1a How can we predict those changes for design and engineering purposes?
		1b How can space exploration advance our knowledge of technologies and processes important on Earth?
		2 What can we learn about the organizing principles from which structure and complexity arise in nature?
		2a How can we apply that knowledge to advance technology?
		3 How will space exploration advance our knowledge of the fundamental laws governing matter, time, space?
		3a What will we learn about the nature of the quantum world?
		3b What will we learn about the nature of gravity, and the relationship between the fundamental forces of physics?
		4 What are the fundamental physical, chemical, and biophysical mechanisms that drive the cellular and psychological behavior observed in the space environment?
		4a How can those changes be used to advance biomedical research?
4	What technology must we create to enable the next explorers to go beyond where we have been?	The content under this question is primarily work that is being undertaken specifically to support needs of the space program, not to advance basic knowledge or to develop concepts for flight experiments.
5	How can we educate and inspire the next generations to take the journey?	Educational Outreach
		Public Outreach

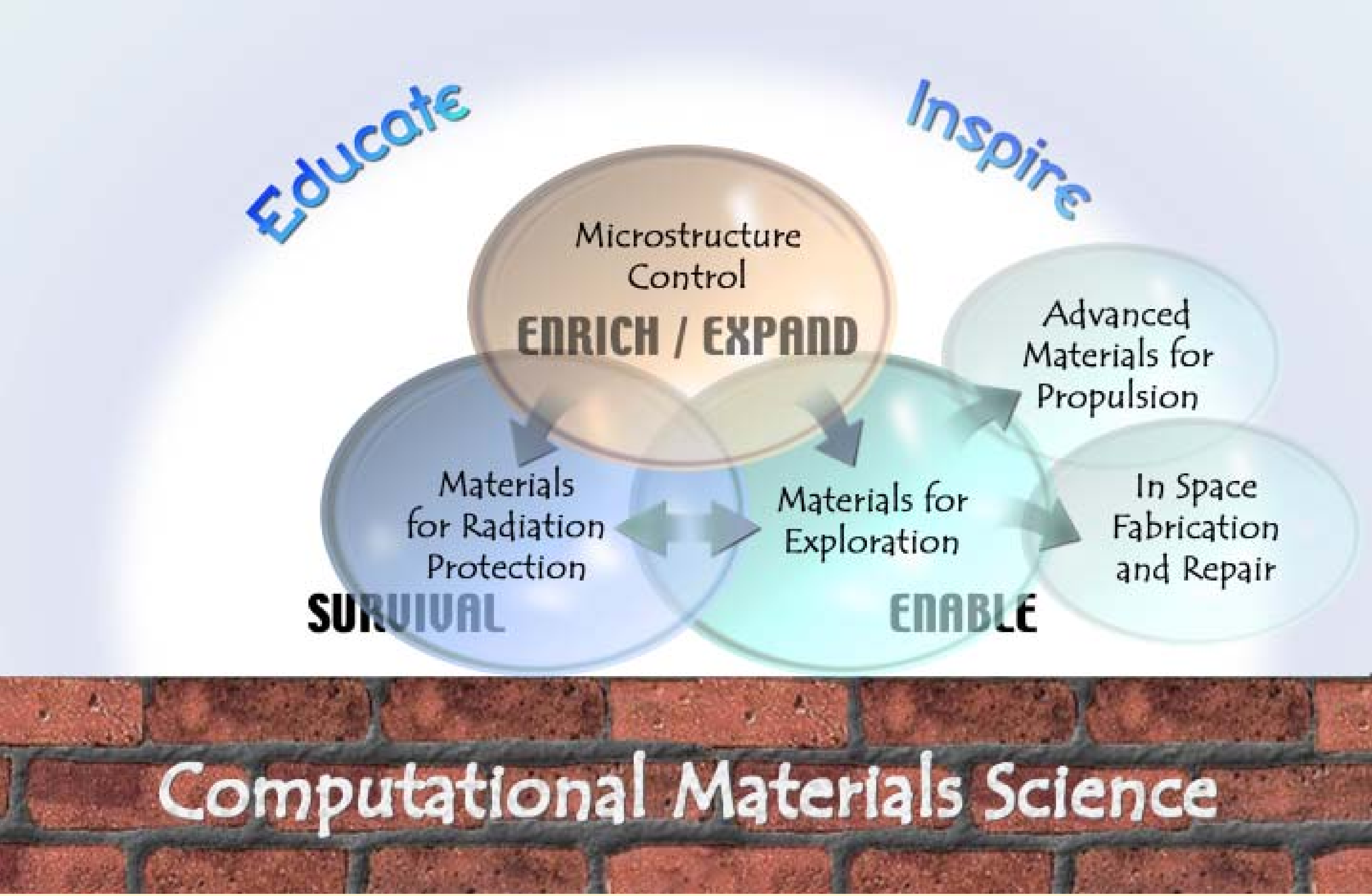
SpaceResearch.nasa.gov

OBPR

Office of Biological & Physical Research

The New Microgravity Program

50% Strategic Research



Nucleation and Metastable States

Fabrication Issues

- **Control of phase transformations (i.e. liquid → solid) is vital to materials science. For example:**
  - fine grain casting – need large numbers of evenly distributed nuclei
  - single crystal growth requires plane front solidification
  - “detached solidification” permits solidification free of a container wall
  - metastable phase can be produced (e.g. diamond, quasicrystals)
  - glass formation by preventing nucleation, including recent verification of nucleation theory (50 years old)

- **In microgravity**
  - One has the ability to provide a containerless environment without applying large external forces

- **Three flight PIs predominantly in this category:**
  - Prof. Day (96 NRA) – University of Missouri-Rolla
  - Prof. Kelton (98 NRA) – Wash U
  - Prof. Flemings (98 NRA) – MIT

Dr. Weber (96 NRA) – Containerless Research Inc.

YAG fibers pulled from levitated (containerless) glass

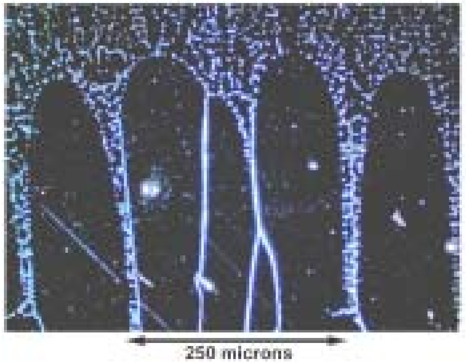
Prediction and Control of Microstructure (Including Pattern Formation and Morphological Stability)

Fabrication/Repair Issues

- **Microstructure governs the properties of a material.**
  - Understanding of factors controlling transition from plane front to cellular to dendritic to homogeneous nucleation. Applicable to directional solidification of elements, alloys, including eutectics, peritectics, monotectics, etc. Structures of soldered, welded components.
  - Need to understand the role of all processing conditions such as thermal profile, growth rate, atmosphere etc. (boundary conditions), the effects of convective/diffusive transport, anisotropy of properties at the solid/liquid (vapor) interface, reactions at a solid/vapor interface.
  - In the absence of convection, microstructure control is more tenable.
  - One major issue is sudden disturbances which can destroy a solid-liquid interface

- **NASA has four flight PIs predominantly in this category:**
  - Prof. Trivedi (two projects – 94 NRA and 98 NRA) – Iowa State
  - Prof. Poirier (94 NRA) – U. AZ
  - Prof. German (96 NRA) – Penn State
  - Prof. Voorhees (94 NRA) – Northwestern

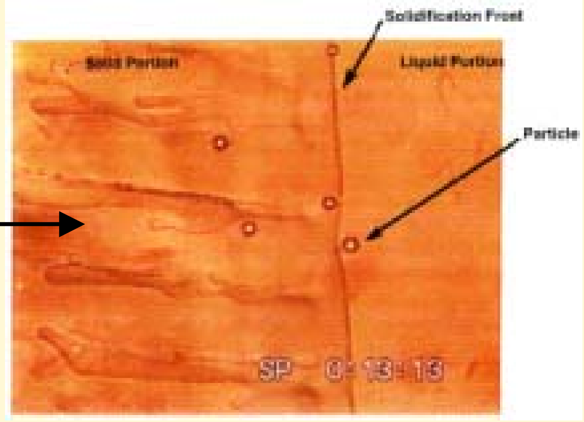
Cellular-dendritic transition studies in directionally solidified high temperature alloys



Phase Separation and Interfacial Phenomena

Fabrication/Repair Issues

- Behavior of interfaces between chemically different phases must be well understood if full advantage is to be taken of the possibilities for fabricating strong two phase materials.
- As an example, the melt of monotectic system divides into two separate liquids on cooling. Sedimentation (difference in density) causes agglomeration; desired fine dispersion of particles will be destroyed. In addition, the wetting behavior may cause complete separation of phases. Directional solidification can be controlled to give aligned two phase structures with desirable properties.
- There is also a need to understand the physics of a liquid-solid front moving through solid particles of a second phase. At such interfaces there is a need to suppress flows driven by temperature and compositional dependence of surface energy.
- With large temperature gradients (as in welding), differences in surface tension will drive Marangoni flows.
- There are three flight PIs predominantly in this category:
  - Prof. Andrews (91 NRA) – UAB
  - Prof. Pojman (96 NRA) – U. of Southern Mississippi
  - Prof. Stefanescu (91 NRA) – U AL



Fundamental studies of MMCs in microgravity

Transport Phenomena

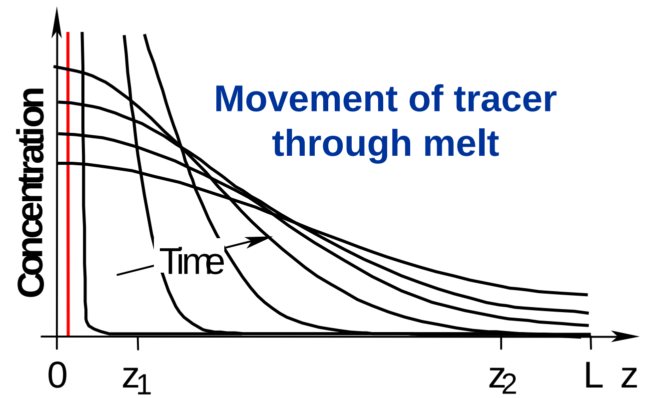
(including process modeling and thermophysical property measurement)

Fabrication/Repair Issues

- **Transport phenomena control the structures of materials which in turn determine their properties.**
- **Heat, mass, momentum transport data are essential for process modeling. There is a paucity of data for liquids, particularly for thermal and solutal diffusivity.**
- **Modeling of processing behavior in low gravity is essential for in-space fabrication and repair.**
- **The OBPR programs in this category have traditionally concentrated both on measuring properties and on establishing transport phenomena physics. Much of this work is computer modeling done in the ground-based research program.**

Convective contamination apparent in diffusion measurements:

⇒ Measurements performed at low-gravity have consistently lower values.



Self-diffusion measurements using a radioactive tracer

Flight experiment on MIR

Prof. Banish – UAH

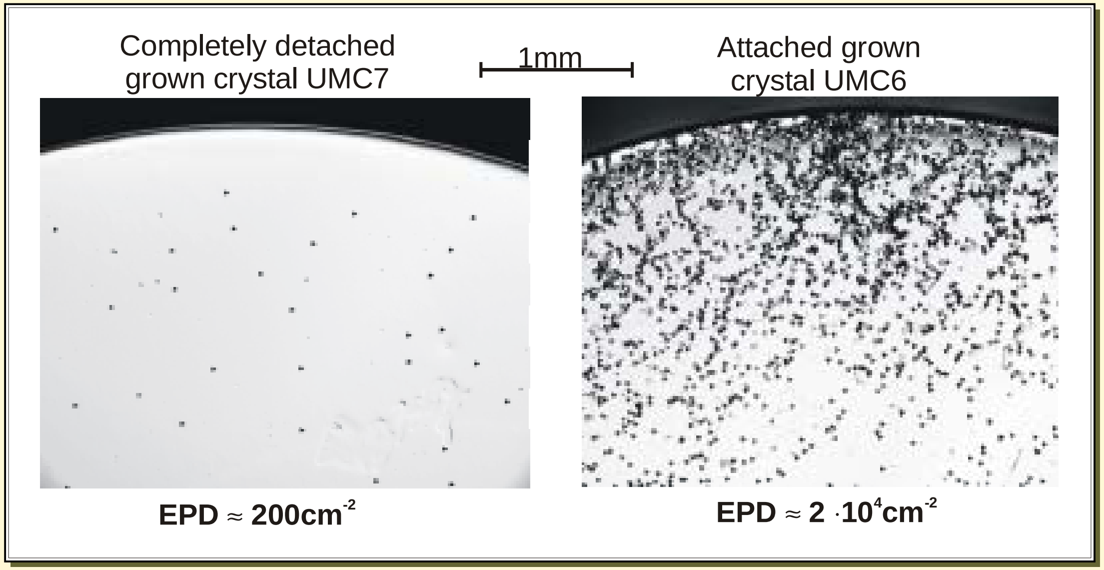
Crystal Growth, and Defect Generation and Control

Fabrication Issues

- Microgravity presents the quiescent environment which allows one to achieve purely diffusion controlled growth. However, free surfaces at different temperatures will exhibit a variation in surface tension; this will drive flow.
- Vapor growth – less density differences, but higher flow rates are taking place.
- Temperature gradients in the liquid are inevitable during directional solidification. Result is density differences in the liquid and buoyancy driven convection when any gravity driven force is present. Solutal gradients will have the same effect.
- Results are macro-segregation (inhomogeneity) and micro-segregation (point defects).

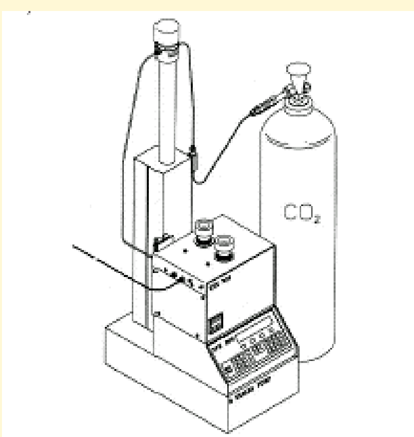
Flight Experiment
Dr. Szofran – MSFC

Directional solidification, and float zone

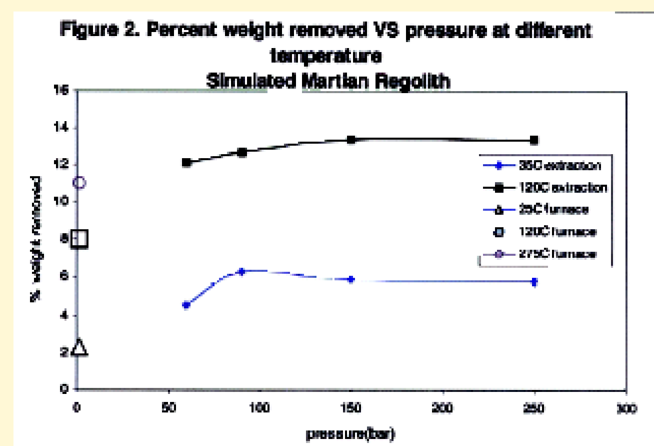


Preliminary In Situ Resource Utilization
Materials Science Projects

Rice, Eric – Orbital Technologies Corporation 96NRA	**Carbon-based Reduction of Lunar Regolith (CRLR)**
Sridhar, K. R. – University of Arizona 96NRA	**Development of Superior Materials for Layered Solid Oxide Electrolyzers Based on Mechanical and Thermal Failure Testing and Analysis**
Debelak, Kenneth – Vanderbilt University 98NRA	**Recovery of Minerals in Martian Soils via Supercritical Fluid Extraction**
Mason, Larry – Lockheed Martin Astronautics 98NRA	**CO(2) Acquisition Membrane (CAM)**
Sadoway, Donald – MIT 98NRA	**From Oxygen Generation to Metal Production: In Situ Resource Utilization by Molten Oxide Electrolysis**



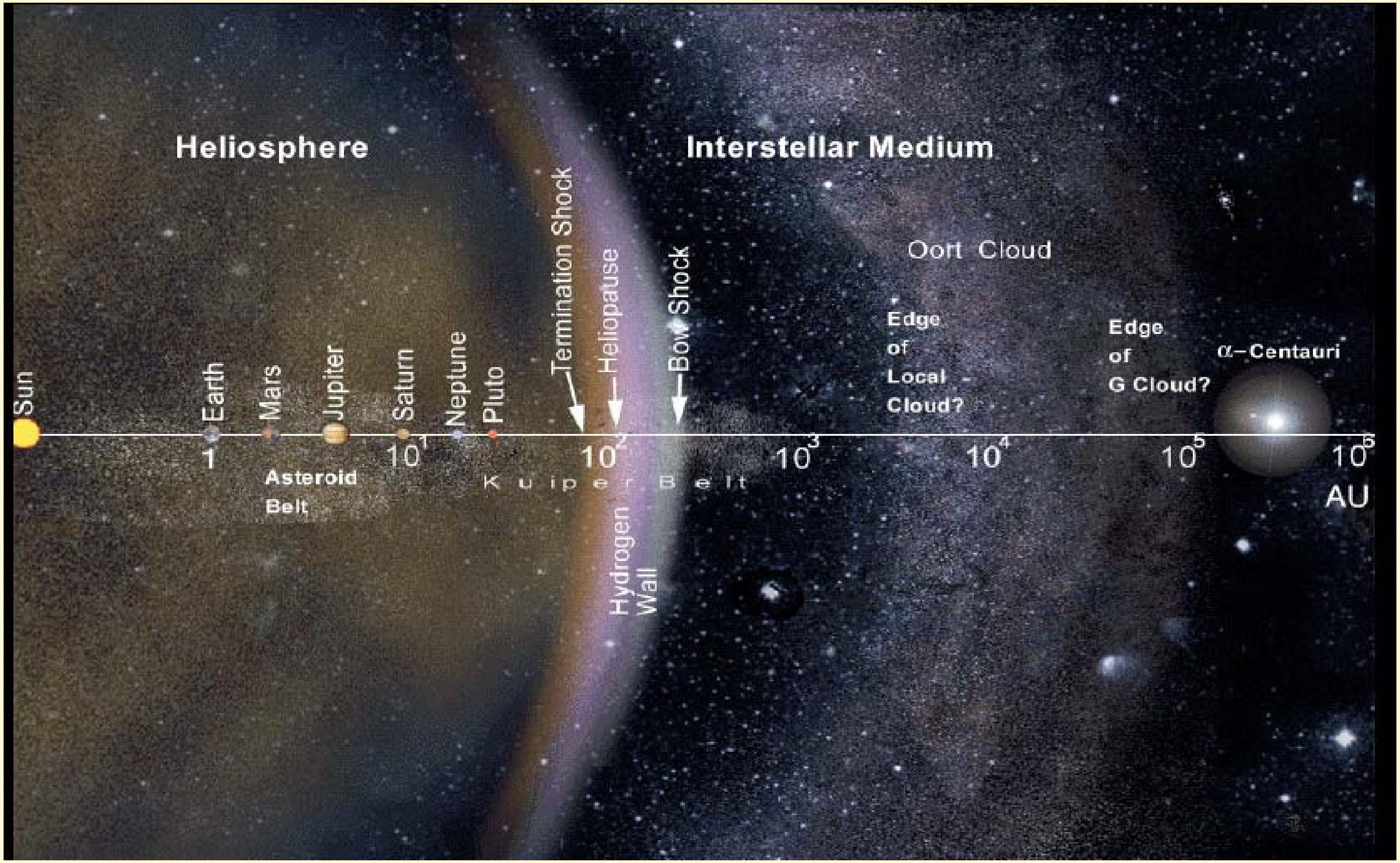
Debelak: Supercritical fluid extraction



Uniqueness of Reduced Gravity on Processing

- **Observations**
  - Significant differences exist between processing on Earth and in microgravity
  - Large data base exists of behavior of materials during processing in microgravity
  - Microgravity Sciences and Application Department (MSAD) has managed a comprehensive program studying the science of the effects of gravity on materials processing
  - Data base is available on line in the form of task book reports at http://research.hq.nasa.gov/taskbook.cfm
  - and in the 2002 Conference Proceedings at http://trs.nis.nasa.gov/archive/00000622/
  - General information about OBPR programs is available at http://spaceresearch.nasa.gov/

Long Duration Processing in Low Gravity



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